Electron Diffraction

1 Objectives

- Electrons as waves.
- Study and verification of the de Broglie hypothesis $\lambda = h/p$.
- Measurement of the spacing of diffracting planes in graphite.

2 Theory

In a bold and daring hypothesis in his 1924 doctoral dissertation Louis de Broglie reasoned that if electromagnetic radiation can be interpreted as *both* particles (Photoelectric Effect, Compton Scattering) and waves (diffraction), then perhaps the electron, which had traditionally been interpreted as a particle, could also have a wave interpretation. De Broglie hypothesized that *all particles* have a wave behavior with a universal relationship between the wavelength and momentum given by $\lambda = h/p$. This expression is called the de Broglie relationship and the wavelength is called the de Broglie wavelength. The momentum in this relationship is the momentum that is conserved in collisions, i.e. the relativistic momentum. The de Broglie relationship holds for all particles. Note that it is identical to the one for photons ($E = h\nu$).

Diffraction phenomena represent clear evidence for wave properties. *How can an electron be both wave and particle?*

In this experiment you will investigate the diffraction of electrons passing through a thin layer of graphite (carbon), which acts as a diffraction grating. It was Max von Laue, who in 1912 suggested (in connection with x-ray studies) that the basic granularity of matter at the atomic level might provide a suitable grating. Lawrence Bragg, using the crystalline structure of NaCl, with a cubic unit cell, first calculated the inter-atomic spacings and showed them to be of the right order for x-rays.

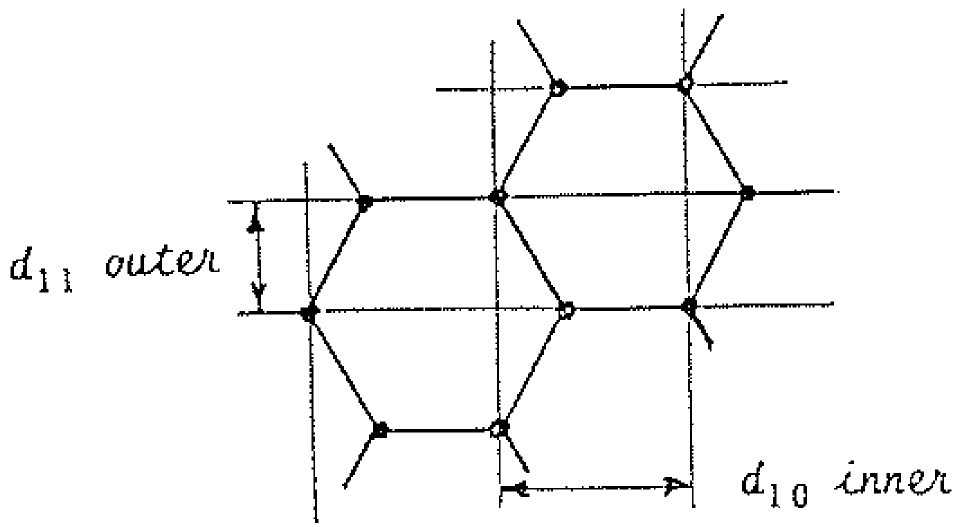

Figure 1: Structure of Graphite

Figure 1 shows the hexagonal structure of graphite used in this experiment with the two characteristic spacings of 0.123 and 0.213 nm. These two spacings will produce two diffraction patterns.

3 Apparatus

Our electron diffraction tube, see Fig. 2, comprises an electron gun which emits a narrow, converging beam of electrons within an evacuated clear glass bulb on the front surface of which is deposited a luminescent screen. Across the exit aperture of the gun lies a micro-mesh nickel grid, onto which a *very* thin layer (only a few molecular layers!) of graphite has been deposited.

The electron beam penetrates through this graphite target to become diffracted into two rings corresponding to the separation of the carbon atoms of 0.123 and 0.213 nm. The diffraction pattern appears as rings due to the polycrystalline nature of graphite. The source of the electron beam is an indirectly-heated oxide-coated cathode.

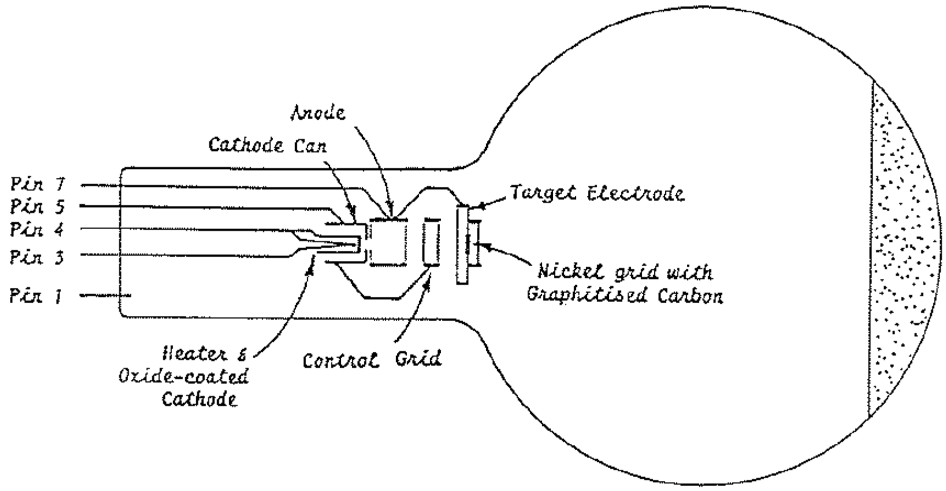

Figure 2: Schematic of the Electron Diffraction Tube

4 Important Precautions

Due to its extreme thinness the graphite can easily be punctured by current overload. Such current overload causes the graphite target to become overheated and to glow dull red. It is therefore important to monitor the anode current and to keep it below 0.25 mA at all times. Use a handheld digital multimeter. In actuality you will likely find that the current tends to stay well below this value, typically a few μA (micro-Amps). Inspect the target periodically during an experiment.

The 33k resistor R in Fig. 3 is incorporated into the filament protection circuit of the stand to provide 'negative auto-bias' and so reduce the likelihood of damage to the target due to accidental abuse. The total emitted current passes through R. Therefore an increase in current causes the cathode-can to become more negatively biased, thereby reducing the emitted current.

5 Experimental Procedure

Connect the tube into the circuit shown in Fig. 3(a) **but ignore** V_B. Both heater supply and HV are obtained from the 813 KeV power unit (U33010). The HV should be connected to the "+" and "−" HV connections to get the full voltage which is read on the top-scale of the KeV unit's meter. Be sure the high voltage slider is at zero before switching on the unit. Switching on the unit (in back) will also switch on the heater. **IMPORTANT:** Switch on the heater supply (V_F), and wait one minute for the cathode temperature to stabilize before

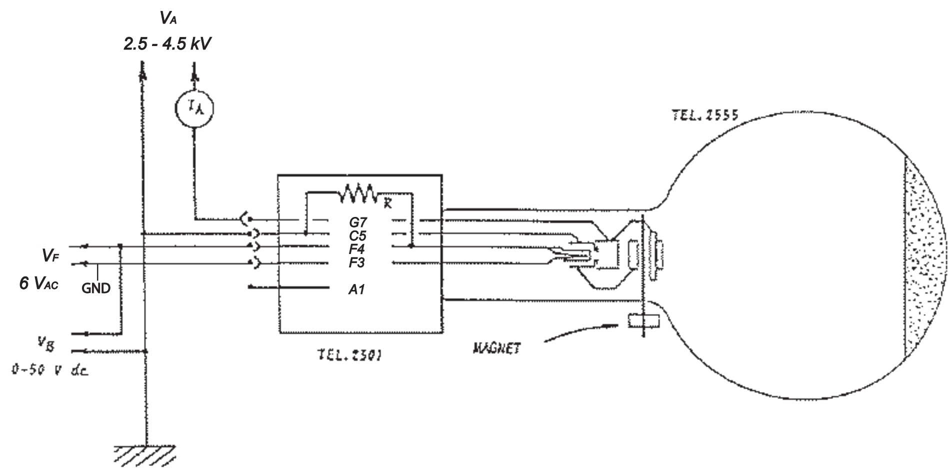

Figure 3: Circuit Diagram

applying the HV (anode voltage V_A).

6 Data Taking and Analysis

Diffraction patters will show as two concentric rings, related to the two characteristic spacings of Graphite. The rings are faint. Be sure the room is very dark. The rings are quite distinct at the full 5 kV, but get very hard to see as you go down in voltage. Try to go as low as 2.5 kV. For each experimental run, take at least 10 different data points measuring the diameter of the two rings with the calipers. And perform at least 4 experimental runs. You can adjust the position of the central spot in the fluorescent screen by using the little magnet on the neck of the tube. Make sure that the rings are centered on the fluorescent screen.

For your data analysis you will need to

• Analyze the geometry of the light bulb. Obtain the relationship between the measured diameter with the extrapolated diameter D. This is necessary for correcting for the curvature (and thickness?) of the glass of the tube-face (see Figure 4). The length of the tube L in Figure 4 is taken as 13.0 ± 0.2 cm.

The kinetic energy and momentum of the electrons are related to the accelerating potential. From Fig. 4 we also know that $D = 2L \tan\theta$, where D is the *extrapolated* diameter, which you need to obtain from your measured diameters.

• By using the de Broglie relation and the diffraction law for a crystalline lattice, derive the equation that relates the lattice spacing d in graphite to the accelerating voltage V_A. Then you can

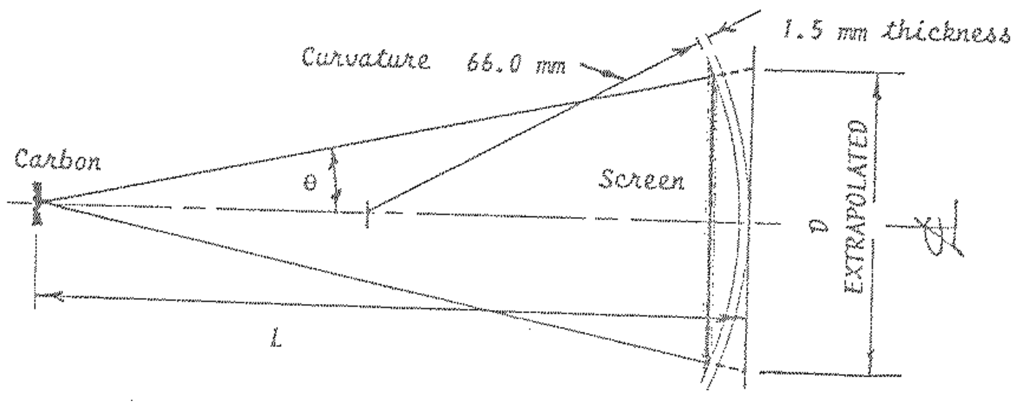

Figure 4: Curvature and glass thickness of the electron diffraction tube. The length $L = 13.0 \pm 0.2$ cm.

use approximations to show that V_A is given approximately by

$$d = \frac{4\pi L\hbar c}{D\sqrt{2eV_A mc^2}} \tag{1}$$

Plot D as a function of $V_A^{-1/2}$ for all your data. Include in your plot the estimated error in D as vertical error bars. The straight lines you should get verify the theory and substantiate de Broglie's hypothesis.

- Calculate the two values for d (d_1 and d_2) from your data (no need to make the above approximation!) and their uncertainties using Eq. (1) and the relation between your measured diameters and D.

- As a second method obtain the spacings d_1 and d_2 from linear fits to Eq. (1).

Compare your two determinations of each characteristic spacing d_1 and d_2 using the methods above with the accepted values of 0.123 and 0.213 nm.

7 References

[1] Melissinos and Napolitano.

Any good Modern Physics textbook.